

## DESCRIPTION

## REFERENCE VOLTAGE GENERATION CIRCUIT

5   **Related Application**

[0001] This application is a national phase of PCT/JP2005/002159 filed on February 14, 2005, which claims priority from Japanese Application No. 2004-122075 filed on April 16, 2004, the disclosures of which Applications are incorporated by reference herein. The benefit of the filing and priority dates of the International and Japanese Applications is  
10   respectfully requested.

**Technical Field**

[0002]     The present invention relates to a reference voltage generation circuit for generating a constant voltage irrespective of a variation in supply voltage or temperature and specifically to a reference voltage generation circuit including a start-up circuit with  
15   which, even if the operation is stabilized at an abnormal stabilization point, the stabilization point is shifted to a normal stabilization point.

**Background Art**

[0003]     Conventionally, the reference voltage generation circuit which generates a constant voltage irrespective of a variation in supply voltage or temperature has been  
20   widely used in analog circuits, such as analog-digital converters, and the like.

[0004]     An example of such a reference voltage generation circuit, illustrated in FIG. 7, has a band gap reference circuit 30 (hereinafter, abbreviated as "BGR circuit"). The BGR circuit 30 includes two diode elements D1 and D2 which have different current densities, three resistive elements R1, R2 and R3, a P-type first transistor Tr1 for supplying a  
25   current to a reference voltage output terminal O, a P-type second transistor Tr2 which determines a drain current flowing through the first transistor Tr1 by a current mirror structure, and a feedback type control circuit 31. The feedback type control circuit 31 is

formed by a differential amplifier circuit **32** and an N-type transistor **Tr3** and controls the drain current of the second transistor **Tr2**.

[0005] The feedback type control circuit **31** functions to stabilize the operation at a stabilization point at which the voltage at a node **N1** (the connection point between the anode of the diode **D1** and the resistive element **R3**) is equal to the voltage at a node **N2** (the connection point between the resistive elements **R1** and **R2**). For example, if the voltage at the node **N1** is higher than that of the node **N2**, the gate voltage of the transistor **Tr3** is increased by the differential amplifier circuit **32**, so that the drain current of the transistor **Tr3** is increased, and the drain current of the second transistor **Tr2** is increased. As a result, the drain current **I1** of the first transistor **Tr1** is increased so that the output voltage of the reference voltage output terminal **O** is increased, and accordingly, the operation shifts to the operation stabilization point. On the contrary, if the voltage at the node **N1** is lower than that of the node **N2**, the gate voltage of the transistor **Tr3** is decreased by the differential amplifier circuit **32**, so that the drain current of the transistor **Tr3** is decreased, and the drain current of the second transistor **Tr2** is decreased. As a result, the drain current **I1** of the first transistor **Tr1** is decreased so that the output voltage of the reference voltage output terminal **O** is decreased, and accordingly, the operation shifts to the operation stabilization point.

[0006] FIG. 8 illustrates the relationship between the output voltage of the reference voltage output terminal **O** and the voltages at the nodes **N1** and **N2**. As seen from FIG. 8, the voltage at the node **N1** is substantially constant so long as the voltage of the reference voltage output terminal **O** is equal to or higher than a predetermined output voltage irrespective of the output voltage value at the reference voltage output terminal **O**. Meanwhile, the voltage at the node **N2** increases as the output voltage of the reference voltage output terminal **O** increases. Therefore, the plots of the voltages at the nodes **N1** and **N2** have an intersection point (normal stabilization point). The feedback type control circuit **31** allows the BGR circuit **30** to operate at the normal stabilization point. As a

result, the BGR circuit **30** is enabled to generate an output voltage independent of the supply voltage.

[0007] The output voltage of the reference voltage output terminal **O** during the operation at the normal stabilization point is expressed by the following formula:

5 [0008] Output Voltage =  $V_d + kT/q \cdot R_2/R_1$   
 $\cdot \log(I_{s2}/I_{s1} \cdot R_2/R_3)$

where  $V_d$  is the voltage across the diode **D1**,  $k$  is Boltzmann constant,  $T$  is temperature,  $q$  is the amount of charges of electrons, and  $I_{s1}$  and  $I_{s2}$  are the saturation currents of the diode elements **D1** and **D2**, respectively. Since voltage  $V_d$  across the diode **D1** has a  
10 negative temperature characteristic, an output voltage independent of the temperature can be generated by setting Voltage  $V_d$  such that the resistance values of the resistive elements **R1**, **R2** and **R3** or the temperature characteristics of currents  $I_{s1}$  and  $I_{s2}$  of the diode elements are canceled with respect to the temperature characteristic of voltage  $V_d$  across the diode **D1**.

15 [0009] As described above, the BGR circuit **30** possesses the advantage of generating an output voltage independent of the supply voltage and temperature. However, as can be seen from FIG. 8, if the output voltage of the reference voltage output terminal **O** is in the lower range, drain current  $I_1$  supplied from the first transistor **Tr1** is very small, and there is an abnormal stabilization point at which the plots of the voltages at the nodes **N1** and **N2**  
20 are crossing. Thus, the feedback type control circuit **31** sometimes controls the operation of the BGR circuit **30** at this abnormal stabilization point. In such a case, the output voltage of the reference voltage output terminal **O** is near the ground potential so that a desired voltage is not output. In view of such, the reference voltage generation circuit shown in FIG. 7 includes a start-up circuit **40** for the BGR circuit **30**. When the operation  
25 is stabilized at the abnormal stabilization point, the start-up circuit **40** allows the BGR circuit **30** to shift its operation from the abnormal stabilization point to the normal stabilization point.

[0010] The conventional start-up circuit **40** has a structure as described in Patent Document 1. A current is supplied from a constant current source **15** to a diode element **16** to generate a diode voltage which is used for determining the normal stabilization point. This diode voltage is compared with the output voltage of the reference voltage output terminal **O** by a comparator circuit **17**. If the output voltage of the reference voltage output terminal **O** is lower than the diode voltage, it is determined that the operation is at the abnormal stabilization point. Accordingly, a P-type transistor **18** is turned ON, and the drain current of the transistor **18** is supplied to the reference voltage output terminal **O**, whereby the output voltage is increased.

10 Alternatively, a start-up circuit described in Patent Document 2 includes a voltage monitoring circuit for monitoring an output voltage. In this structure, if the voltage monitoring circuit determines that the operation is at the abnormal stabilization point, voltages are supplied to the reference voltage output terminal **O** and the node **N1**.

[0011] Thus, in the conventional start-up circuits, the output voltage of the reference voltage output terminal **O** is monitored all the time. In case of abnormal conditions, the voltage of the reference voltage output terminal **O** is increased such that the operation is shifted from the abnormal stabilization point to the normal stabilization point.

Patent Document 1: Gazette of Japanese Patent No. 3422706 (Figure 1)

Patent Document 2: Gazette of Japanese Patent No. 3185698 (Figure 1)

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## **Disclosure of Invention**

### **Problems to be solved by the invention**

[0012] However, in the conventional start-up circuits, it is necessary to monitor the output voltage of the reference voltage output terminal **O** all the time, and therefore, the current is disadvantageously consumed by the monitoring circuit all the time. For example, in Patent Document 1, the currents are consumed by the current source **15** which generates the diode voltage and the comparator circuit **17** which compares the diode

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voltage with the output voltage. In Patent Document 2, the current is consumed by the voltage monitoring circuit which monitors the output voltage of the reference voltage output terminal. For example, in a battery-driven portable device including such a reference voltage generation circuit, such current consumptions disadvantageously shorten the battery duration of the portable device.

[0013] In the conventional start-up circuits, a relatively large number of semiconductor elements are used in the monitoring circuit, etc. For example, specifically, the comparator circuit 17 included in the start-up circuit 40 illustrated in FIG. 7 is realized by a differential amplifier circuit including a large number of semiconductor elements as shown in FIG. 9. To form such many semiconductor elements over a semiconductor substrate, it is necessary to secure a large area, which leads to high cost.

[0014] In view of the above circumstances, an objective of the present invention is to provide, in a reference voltage generation circuit, a start-up circuit which does not incur an increase in current consumption and which is capable of being realized by a smaller number of elements within a smaller circuit area.

#### **Means for Solving the Problems**

[0015] To solve the above problems, the present inventors noted the fact that, in the BGR circuit illustrated in FIG. 7, among the first and second P-type transistors which form a current mirror circuit, the drain current of the second P-type transistor **Tr2** is zero at the abnormal stabilization point. In a reference voltage generation circuit according to the present invention, in the case of such a situation, the drain current of the second P-type transistor **Tr2** is forced by the start-up circuit to flow. Then, this increase in drain current also increases the drain current of the first P-type transistor so that the output voltage of the reference voltage output terminal is increased. Accordingly, a large portion of the drain current of the second P-type transistor **Tr2** flows into the feedback type control circuit. As a result, the current flowing into the start-up circuit is restricted to a small size.

Specifically, a reference voltage generation circuit of the present invention is a reference voltage generation circuit for generating a constant reference voltage at a reference voltage output terminal, comprising: a first diode element having a cathode connected to a ground potential; a second diode element which has a current density different from that of the first diode element and whose cathode is connected to the ground potential; a first resistive element having an end connected to an anode of the second diode element; a second resistive element having an end connected to the other end of the first resistive element, the other end of the second resistive element being connected to the reference voltage output terminal; a third resistive element having an end connected to the anode of the first diode element and the other end connected to the reference voltage output terminal; a first P-type transistor for supplying a current to the reference voltage output terminal; a second P-type transistor having a gate terminal connected to its own drain terminal and to a gate terminal of the first P-type transistor; a bandgap reference circuit having a feedback type control circuit for controlling a drain current of the second P-type transistor such that a voltage at the anode of the first diode element is equal to a voltage at a connection point between the first and second resistive elements; and a start-up circuit for, if an output voltage of the reference voltage output terminal of the bandgap reference circuit is at an abnormal stabilization point, shifting the output voltage from the abnormal stabilization point to a normal stabilization point, wherein the start-up circuit is provided between the drain terminal of the second P-type transistor of the bandgap reference circuit and the ground potential, a current consumed by the start-up circuit is supplied from the drain terminal of the second P-type transistor, and if the drain current of the second P-type transistor is substantially zero, the start-up circuit increases the drain current of the second P-type transistor.

[0017] According to the present invention, in the reference voltage generation circuit, the start-up circuit is a P-type transistor whose gate terminal is connected to the reference voltage output terminal.

[0018] According to the present invention, in the reference voltage generation circuit, the start-up circuit includes: a P-type transistor having a gate terminal connected to the reference voltage output terminal; and a current generating element provided between a source terminal of the P-type transistor and a drain terminal of the second P-type transistor  
5 of the bandgap reference circuit.

[0019] According to the present invention, in the reference voltage generation circuit, the current generating element is a resistive element.

[0020] According to the present invention, in the reference voltage generation circuit, the current generating element is a diode element.

10 [0021] According to the present invention, in the reference voltage generation circuit, the current generating element is a transistor whose gate terminal is connected to a drain terminal.

[0022] According to the present invention, in the reference voltage generation circuit, the current generating element is a transistor whose gate terminal is fixed to a constant  
15 voltage.

[0023] With the above features of the present invention, when the bandgap reference circuit is at the abnormal stabilization point, the drain current of the second P-type transistor is substantially zero. However, since the start-up circuit increases the drain current, in the bandgap reference circuit, the drain current of the first P-type transistor  
20 increases, and the output voltage of the reference voltage output terminal also increases. Accordingly, the feedback type control circuit controls the output voltage of the reference voltage output terminal to be stabilized at the normal stabilization point. At this normal stabilization point, almost all of the drain current of the second P-type transistor flows into the feedback type control circuit, while the value of a current flowing into the start-up  
25 circuit is small, and therefore, the current consumption is small.

[0024] Specifically, according to the present invention, when the reference voltage output terminal is at the abnormal stabilization point, the voltage of the reference voltage

output terminal is at a level near the ground potential. However, at this point in time, the P-type transistor included in the start-up circuit has a large gate-source voltage. Thus, the drain current of the second P-type transistor of the bandgap reference circuit is effectively increased, and as a result, the output voltage of the reference voltage output terminal quickly increases, so that the feedback type control circuit controls the bandgap reference circuit to operate at the normal stabilization point.

[0025] According to the present invention, the start-up circuit is formed by a series circuit consisting of a P-type transistor and a current generating circuit. Thus, the value of a current flowing through the start-up circuit can be limited to a value smaller than the value of the drain current of the first P-type transistor at the normal stabilization point of the bandgap reference circuit. Therefore, the operation at the normal stabilization point can readily be secured.

#### **Effects of the Invention**

[0026] As described above, according to a reference voltage generation circuit of the present invention, the start-up function can be realized without a substantial increase in current consumption, while relatively complicated circuits conventionally necessary, such as a comparator circuit, a voltage monitoring circuit, and the like, can be omitted, such that the number of elements and layout area are decreased, and accordingly, the size and cost of the circuit are decreased.

#### **Brief Description of Drawings**

[0027] FIG. 1 is a circuit diagram showing a reference voltage generation circuit according to embodiment 1 of the present invention.

FIG. 2 is a graph which shows transitions of the output voltage, drain currents of transistors, etc., during the passage from abnormal stabilization point to normal stabilization point in the reference voltage generation circuit.



FIG. 3 is a circuit diagram showing a reference voltage generation circuit according to embodiment 2 of the present invention.

FIG. 4 is a circuit diagram showing a reference voltage generation circuit according to embodiment 3 of the present invention.

5           FIG. 5 is a circuit diagram showing a reference voltage generation circuit according to embodiment 4 of the present invention.

FIG. 6 is a circuit diagram showing a variation of the reference voltage generation circuit according to embodiment 4.

10          FIG. 7 is a circuit diagram showing an example of a conventional reference voltage generation circuit.

FIG. 8 is a graph illustrating abnormal stabilization point and normal stabilization point in a bandgap reference circuit.

FIG. 9 is a circuit diagram showing a structure of a differential amplifier circuit used in a start-up circuit of the conventional reference voltage generation circuit.

15   **Description of Reference Numerals**

20	[0028]	1	BGR circuit
		2, 2A to 2D	Pull down circuit (Start-up circuit)
		D1	First diode element
		D2	Second diode element
		D3	Diode element (Current generating element)
		R1	First resistive element
		R2	Second resistive element
		R3	Third resistive element
		R4	Resistive element (Current generating element)
	25	O	Reference voltage output terminal
		Tr1	First P-type transistor
		Tr2	Second P-type transistor

	Tr3	Transistor
	Tr4	P-type transistor
	Tr5, Tr6	P-type transistor (Current generating element)
	11	Feedback type control circuit
5	14	Differential amplifier circuit

### **Best Mode for Carrying Out the Invention**

[0029] Hereinafter, embodiments of the present invention will be described with reference to the drawings.

10 [0030] (Embodiment 1)

FIG. 1 shows a reference voltage generation circuit according to embodiment 1 of the present invention.

[0031] In FIG. 1, reference numeral 1 denotes a BGR circuit, and reference numeral 2 denotes a pull down circuit which serves as a start-up circuit. The BGR circuit 1 has a  
15 reference voltage output terminal O for outputting a constant reference voltage.

[0032] In the BGR circuit 1, reference numeral D1 denotes a first diode element, reference numeral D2 denotes a second diode element, reference numeral R1 denotes a first resistive element, reference numeral R2 denotes a second resistive element, reference numeral R3 denotes a third resistive element, reference numeral Tr1 denotes a P-type first  
20 transistor, reference numeral Tr2 denotes a P-type second transistor, and reference numeral 11 denotes a feedback type control circuit. The cathode of the first diode element D1 is connected to a ground potential. The current density of the second diode element D2 is different from that of the first diode element D1. The cathode of the second diode element D2 is connected to the ground potential. One end of the first  
25 resistive element R1 is connected to the anode of the second diode element D2. The other end of the first resistive element R1 is connected to one end of the second resistive element R2. The other end of the second resistive element R2 is connected to the

reference voltage output terminal **O**. One end of the third resistive element **R3** is connected to the anode of the first diode element **D1**. The other end of the third resistive element **R3** is connected to the reference voltage output terminal **O**.

[0033] The first P-type transistor **Tr1** has a source terminal connected to a power supply and a drain terminal connected to the reference voltage output terminal **O** and supplies a current to the reference voltage output terminal **O**. The second P-type transistor **Tr2** and the first P-type transistor **Tr1** form a current mirror circuit. The second P-type transistor **Tr2** has a source terminal connected to the power supply and a gate terminal connected to its own drain terminal and to the gate terminal of the first P-type transistor **Tr1**. The second P-type transistor **Tr2** determines drain current **I1** flowing through the first P-type transistor **Tr1**. The feedback type control circuit **11** controls drain current **I2** of the second P-type transistor **Tr2** such that the voltage at the anode of the first diode element **D1** (hereinafter, "node **N1**") is equal to the voltage at the connection point between the first resistive element **R1** and the second resistive element **R2** (hereinafter, "node **N2**"). The feedback type control circuit **11** has an N-type transistor **Tr3** and a differential amplifier circuit **14**. The transistor **Tr3** has a source terminal connected to the ground potential and a drain terminal connected to the drain terminal of the second P-type transistor **Tr2** (hereinafter, "node **N3**"). The voltages at the two nodes **N1** and **N2** are input to the differential amplifier circuit **14**. The output of the differential amplifier circuit **14** is applied to the gate terminal of the transistor **Tr3**.

[0034] When the output voltage of the reference voltage output terminal **O** of the BGR circuit **1** is at the abnormal stabilization point illustrated in FIG. 8, the pull down circuit **2** shifts the output voltage to the normal stabilization point. The pull down circuit **2** has a P-type transistor **Tr4**. The P-type transistor **Tr4** is provided between the drain terminal of the second P-type transistor **Tr2** of the BGR circuit **1** (i.e., node **N3**) and the ground potential. The gate terminal of the P-type transistor **Tr4** is connected to the reference voltage output terminal **O** of the BGR circuit **1**. When the value of drain current **I2** of the

second P-type transistor **Tr2** of the BGR circuit **1** is substantially zero, the P-type transistor **Tr4** increases drain current  $I_2$ .

[0035] Now, the operation of this embodiment is described. It is assumed herein that the size of the first P-type transistor **Tr1** is equal to that of the second P-type transistor **Tr2** and that drain currents  $I_1$  and  $I_2$  of these transistors **Tr1** and **Tr2** satisfy the relationship of  $I_1=I_2$  because of the current mirror structure. Hereinafter, the operation of the BGR circuit **1** shifting from the abnormal stabilization point to the normal stabilization point is described with reference to FIG. 1 and FIG. 2.

[0036] First, the operation is at the abnormal stabilization point, in which the output voltage of the reference voltage output terminal **O** is at a level near the ground potential. At this point in time, the voltage at the output terminal of the differential amplifier circuit **14** of the feedback type control circuit **11**, i.e., the voltage at the gate terminal of the transistor **Tr3** (node **N4**), is 0 V so that the transistor **Tr3** is OFF. Therefore, drain current  $I_3$  of the transistor **Tr3** is  $I_3=I_2=I_1=0(A)$ . Thus, the output voltage of the reference voltage output terminal **O** is maintained at the ground potential. Meanwhile, the drain terminal of the second P-type transistor **Tr2** is pulled-up to the supply potential because the transistor **Tr3** is OFF.

[0037] When the BGR circuit **1** is at the abnormal stabilization point as described above, in the pull down circuit **2**, the gate terminal of the P-type transistor **Tr4** is at the ground potential, the source terminal of the P-type transistor **Tr4** is at the supply potential, and the gate-source voltage is at the supply potential. Accordingly, the transistor **Tr4** is turned ON so that current  $I_2$  ( $=I_4$ ) starts to flow from the second P-type transistor **Tr2** of the BGR circuit **1**. Since the first P-type transistor **Tr1** of the BGR circuit **1** generates a mirrored current of current  $I_2$  of the second P-type transistor **Tr2**, current  $I_1$  starts to flow through the first P-type transistor **Tr1**. As a result, the output voltage of the reference voltage output terminal **O** rises to an intermediate voltage between the abnormal stabilization point and the normal stabilization point.

[0038] When the output voltage of the reference voltage output terminal **O** rises to the intermediate voltage so that the voltage at the node **N1** is higher than the voltage at the node **N2**, the differential amplifier circuit **14** of the feedback type control circuit **11** increases the gate voltage of the N-type transistor **Tr3** such that the voltage at the node **N1** is equal to the voltage at the node **N2**. Since the differential amplifier circuit **14** generally has a slow response speed because of reduction in current consumption, drain current  $I_3$  of the transistor **Tr3** is zero ( $I_3=0$ ) before the voltage at the gate terminal of the transistor **Tr3** (node **N4**) exceeds the threshold voltage of the transistor **Tr3**. This interval corresponds to Transient State (1) of FIG. 2.

10 [0039] Thereafter, when the gate voltage of the transistor **Tr3** exceeds the threshold voltage of the transistor **Tr3**, drain current  $I_3$  starts to flow. Accordingly, drain current  $I_1$  of the first P-type transistor **Tr1** starts to increase, and the output voltage of the reference voltage output terminal **O** increases. Since the increase of the output voltage of the reference voltage output terminal **O** results in a smaller gate-source voltage of the transistor **Tr4** of the pull down circuit **2**, drain current  $I_4$  of the transistor **Tr4** decreases. This interval corresponds to Transient State (2) of FIG. 2.

[0040] When the output voltage of the reference voltage output terminal **O** then reaches a level corresponding to the normal stabilization point, the differential amplifier circuit **14** ceases the control of increasing the gate voltage of the transistor **Tr3**. Therefore, the output voltage of the reference voltage output terminal **O** becomes constant. This interval corresponds to Normal State of FIG. 2. In this interval, drain currents  $I_1$  to  $I_4$  of the four transistors **Tr1** to **Tr4** have the relationship of  $I_1=I_2=I_3+I_4$ . The increment of drain current  $I_4$  consumed by the pull down circuit **2** is equal to the decrement of drain current  $I_3$  of the transistor **Tr3** of the BGR circuit **1**. This means that the start-up function is realized without a substantial current increase.

25 [0041] In the above-described manner, drain current  $I_2$  of the second P-type transistor **Tr2** of the BGR circuit **1** is also forced to flow through the pull down circuit **2** in

addition to current I3 controlled by the feedback type control circuit 11. When current I4 flowing through the pull down circuit 2 increases, current I3 controlled by the feedback type control circuit 11 is decreased. On the contrary, when current I4 flowing through the pull down circuit 2 decreases, current I3 controlled by the feedback type control circuit 11 is increased by an amount corresponding to the decrement of current I4. In such a manner, the BGR circuit 1 can operate at the normal stabilization point all the time.

[0042] In this example, the pull down circuit 2 is realized by a single piece of transistor Tr4. Therefore, this embodiment provides the great benefit of layout area reduction.

10 [0043] (Embodiment 2)

Embodiment 2 of the present invention is illustrated in FIG. 3.

[0044] If in embodiment 1 current I4 flowing through the pull down circuit 2 is greater than drain current I1 of the first P-type transistor Tr1 which is required in the BGR circuit 1 during the normal state, drain current I1 of the first P-type transistor Tr1 exceeds a current value which is required during the normal state, so that the BGR circuit 1 does not operate at the normal stabilization point. To avoid this trouble, it is necessary to optimize the transistor size of the P-type transistor Tr4 of the pull down circuit 2 such that current I4 flowing through the pull down circuit 2 is smaller than drain current I1 of the first P-type transistor Tr1 in the normal state. However, current I4 flowing through the P-type transistor Tr4 at the abnormal stabilization point is proportional to the square of the supply voltage which determines the gate-source voltage of the P-type transistor Tr4. Further, the fabrication process of the transistor is generally complicated so that the drain current readily varies. Because of such disadvantages, it is relatively difficult to determine the size of the P-type transistor Tr4 such that the above-described relationship of “current I4 < current I1 in normal state” is satisfied.

[0045] In view of such, a pull down circuit 2A of embodiment 2 includes a resistive element (current generating element) R4 in addition to the P-type transistor Tr4 as

illustrated in FIG. 3. This resistive element **R 4** has an end connected to the source terminal of the P-type transistor **Tr4** and the other end connected to the drain terminal of the second P-type transistor **Tr2** of the BGR circuit 1 (node **N3**).

[0046] In embodiment 2, the basic principle of the start-up function realized by the pull down circuit **2A** is the same as that of embodiment 1. In embodiment 2, current **I4** flowing through the pull down circuit **2A** is determined by the resistance value of the resistive element **R4**. Specifically, current **I4** flowing through the pull down circuit **2A** has a value obtained by dividing the value of the following formula by the resistance value of the resistive element **R4**:

10           Voltage at node **N3** – (output voltage of reference voltage output terminal **O**  
              – threshold voltage of transistor **Tr4**).

As a result, current **I4** is proportional to the supply voltage (which determines the voltage at the node **N3**) raised to the first power. Thus, the design which satisfies the above-described relationship of “current **I4** < current **I1** in normal state” is readily achieved.

15           [0047]     (Embodiment 3)

Embodiment 3 of the present invention is illustrated in FIG. 4.

[0048] In embodiment 3, a pull down circuit **2B** is formed by connecting the P-type transistor **Tr4** and a diode element (current generating element) **D3** in series. The diode element **D3** has an anode connected to the node **N3** of the BGR circuit 1 and a cathode connected to the source terminal of the P-type transistor **Tr4**. The other components are the same as those of embodiment 1. Therefore, like elements are denoted by like reference numerals, and the descriptions thereof are herein omitted.

[0049] In embodiment 3, current **I4** flowing through the pull down circuit **2B** has a value obtained by dividing the value of the following formula by the interterminal impedance of the diode element **D3**:

Voltage at node **N3** – (output voltage of reference voltage output terminal **O**  
– threshold voltage of transistor **Tr4**).

In this case, the dependence on the power supply which determines the voltage of the node **N3** of the BGR circuit **1** is large as compared with the example of embodiment 2 which uses the resistive element **R4**. However, since the diode element **D3** generally has a small variation, the design which satisfies the above-described relationship of “current  $I_4$  < current  $I_1$  in normal state” is more readily achieved.

[0050] (Embodiment 4)

Embodiment 4 of the present invention is illustrated in FIG. 5.

10 [0051] In embodiment 4, a pull down circuit **2C** is formed by connecting the P-type transistor **Tr4** and another P-type transistor (current generating element) **Tr5** in series. The P-type transistor **Tr5** has a source terminal connected to the node **N3** of the BGR circuit **1** and a drain terminal connected to its own gate terminal and to the source terminal of the P-type transistor **Tr4**.

15 [0052] In embodiment 4, current  $I_4$  flowing through the pull down circuit **2C** has a value obtained by dividing the value of the following formula by the impedance between the source and drain terminals of the transistor **Tr5**:

Voltage at node **N3** – (output voltage of reference voltage output terminal **O**  
– threshold voltage of transistor **Tr4**).

20 In embodiment 4, the pull down circuit **2C** can be constructed by only two transistors, i.e., the transistors **Tr4** and **Tr5**. Therefore, it is not necessary to consider the characteristics of the resistive element **R4** or the diode element **D3** as is in embodiments 2 and 3.

[0053] Although in embodiment 4 the gate terminal of the transistor **Tr5** is connected to the drain terminal, a transistor (current generating element) **Tr6** whose gate terminal is connected to a constantly fixed voltage, such as the ground, or the like, may be provided instead as shown in FIG. 6. The same function as that of embodiment 3 can also be

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realized even when the impedance between the source and drain of the transistor **Tr6** is used.

**Industrial Applicability**

5 [0054] As described above, according to the present invention, the start-up function can be realized by a smaller number of elements without increasing the current consumption. Therefore, in an application to a portable device, or the like, the life of a battery can be extended, while the layout area can be effectively reduced. Thus, the present invention is useful as a reference voltage generation circuit, or the like, which is  
10 effective for reduction in size and cost.